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14. ABSTRACT
The learning of the deployment of transient attention is an entirely new yet robust phenomenon. We found that it is mediated by a unique primitive short term memory system which learns features, not objects. Yet it is object centered and not retinotopic. This learning is graded, incremental and short lived.
We also investigated longer term perceptual learning: very short naps during the afternoon can enhance perceptual learning dramatically, that in some cases beneficial effects are as good as a whole nights sleep. We suggest that for a nap to be beneficial it must contain both SWS and REM. In terms of a neurophysiological substrate, the learning must be occurring in the early visual areas because the effects are restricted to the specific visual quadrants stimulated.
The other main focus of the work has been the role of learning of attentional deployment on motor behavior, in particular arm movements. There seems to be a direct coupling between the deployment of focal attention and action, the speed of motor activities is determined by the deployment of focal attention. Less expected, are results indicating that the planning and execution of motor actions are not separable. Decisions are often countermanded by mid-stream changes in motor actions with little cost in speed or accuracy indicating that the combined brain and motor plant is adept at parallel processing of simultaneous motor commands.

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Final Report
Implicit memory, perception and the rapid deployment of visual attention and action

Period January 1, 2001 – March 31, 2004.

Executive Summary

The issue of learning and memory in perception and in the deployment of visual attention was examined in considerable detail, with 7 of the 14 papers published resulting from work done in this area. This included an investigation learning of the deployment of visual attention itself and perceptual learning more broadly. Learning of the deployment of transient attention is an entirely new yet robust phenomenon. It is mediated by a unique short term memory system which is primitive, which learns only features and not objects. Yet it is object centered and not retinotopic. Furthermore the learning is graded, incremental and short lived no more than 30 seconds. It is based on a primitive memory kernel which summates linearly.

We have also discovered with respect to longer term perceptual learning that very short naps during the afternoon can enhance perceptual learning dramatically, that in some cases beneficial effects are as good as a whole nights sleep. We suggest that for a nap to be beneficial it must contain both SWS and REM. Afternoon naps fulfill this requirement. In terms of a neurophysiological substrate, the learning must be occurring in the early visual areas because the effects are restricted to the specific visual quadrants stimulated.

The other main focus of the work has been the role of learning of attentional deployment on motor behavior, in particular arm movements. In this area, we have two main findings. First that there seems to be a direct coupling between the deployment of focal attention and action, that the speed of motor activities is determined by the deployment of focal attention. Second, and less expected, are results indicating that the planning and execution of motor actions are not separable. Decisions are often countermanded by mid-stream changes in motor actions. This can occur with surprisingly little cost in speed or accuracy indicating that the combined brain and motor plant is adept at parallel processing of simultaneous motor commands. Since the physical context of any motor act is dependent dynamically dependent on the state of the motor plant, this raises the question as to how successive motor acts planned in parallel are executed. Is the physical context of each successive motor act determined purely by assessing the state of the motor plant or is feedforward information from simultaneously planned motor actions also relevant?

Technical Summary

Learning of transient attentional deployment.

The main effort has been to characterize the learning of transient attentional deployment, an unexplored phenomenon with broad implications for perception and action. Our basic findings are as follows: We have short term memory mechanisms in our brain which enables attention to go more efficiently to targets attended to in the very recent past (30 seconds). This allows attention to go to loci in the environment with much greater speed. The memory system has many striking characteristics. (1) it learns very quickly, reaching asymptotic performance within 4-8 attentional fixations (Kristjansson et al, 2001). (2) it is restricted to just one kind of attentional deployment, a very fast powerful transient attentional system (Kristjansson and Nakayama, 2001). (3) the system is involuntary, it cannot be countermanded or overridden (Kristjansson et al., 2001). (4) it is very primitive, the associations are to features and not objects. The memory system for example cannot speed focal attention to one end of one object and the other end of a different object. Thus it can learn only to go to simple features or object centered loci (right or left), it cannot learn about objects themselves

(Kristjansson and Nakayama, 2003 Nakayama et al., 2004) . (5) the memory is graded, incremental and summates linearly. It can be described in terms of the superposition of a single memory kernel function, which decays exponentially over time (Nakayama et al, 2004) . (6) it is object centered, it is not dependent of retinotopy (Kristjansson et al., 2001, Nakayama et al., 2004). (8) the system represents new kind of associative memory system, heretofore unexplored , linking the act of attentional deployment to features in the visual environment. The linkage to features is piecemeal with multiple associations to many features simultaneously and independently.

The existence of such a system has ramifications. First, it has implications regarding neural function. No memory neurobiological memory systems with this time scale have been identified but with such a characteristic signature, we think that there is a good chance that a neural locus can be identified. This could have the twin benefits of providing a new learning preparation to examine as well as elucidating the network characteristics of this remarkably robust system.

In our summary chapter (Nakayama et al. 2004) we suggest that the associative learning system identified should be considered more precisely as modulating in the short term, existing associative connections. The time scale of the memory process suggests the possibility of qualitatively different underlying mechanisms. The learning curve, while showing the typical negative accelerating function is qualitatively different from conventional learning processes where incremental learning strength is proportional to the remaining learning capacity (Rescorla and Wagner,1972). In the current memory system, there is no diminution of added learning strength, the negative accelerating learning curve results from a different mechanism, that of the memory kernel's exponential decay. Second, the existence of this memory system is unusual in that it mediates a very fast response. The deployment of focal attention has a latency short extremely short, below 50 milliseconds. Thus even though the deployment of focal attention seems reflex like, it has unsuspected flexibility.

The fact, however, that the memory system is object centered but does not learn about objects is puzzling. As such, the neural basis of this form of plasticity is bound to be revealing about underlying neural mechanisms. Third, the existence of this system is bound to have many implications regarding function. We suggest several. The system provides an alternative to the widely accepted notion of "search image postulated to account for many aspects of animal foraging. Instead of a search image, we think our implicit memory system can account for the foraging literature in simpler mechanistic terms. In addition, we think that the memory seen portends the existence of similar systems mediating a wide range of cognitive and motor functions. For example, there is a large literature on task switching where there is a large penalty paid for switching any aspect of a repetitive task. Generalizing our memory kernel to these other processes could provide a simple account of all these examples. Finally there is the issue of "reinforcement" or reward, what enables the system to strengthen some associations and not others. We have evidence that it is the act of deploying attention in a competitive situation that is of importance. Simply directing attention to a single target for example, does not lead that target's feature to become strongly associated with increased speed later on.

Naps and perceptual learning

Two papers which comprised Sara Mednick's Ph.D. dissertation (Mednick et al. 2002, 2003), show an important role for afternoon naps in preventing perceptual deterioration in repeated tasks as well as in improving subsequent performance. The task was a texture discrimination task where the observer was to identify the orientation of an embedded texture within a larger textured field. Our first important finding was that perception in a repeated tasks dramatically deteriorated during the day as a consequence of over practice. We then found that this deterioration could be completely abolished by a short nap in the afternoon. In a second paper, we examined another aspect of this same phenomenon, the importance of short afternoon naps in facilitating learning. In both cases, for the deterioration and for the facilitation of learning, the beneficial effects of a nap had two important characteristics. First, the effects were retinotopic, that is that the effect of the nap was to either prevent deterioration or improve performance only within a particular quadrant of the visual field. This indicates that the site of sleep enhanced learning is very early in the visual pathway, in those areas of the visual cortex that have preserved retinotopic maps. Second the results indicate that the effect for improvement is very large, a short nap has as much effect in perceptual improvement as does a full 6 hours over overnight sleep.

There are several aspects of the research that are of importance. It is the first series of studies to show that daytime naps, not a full night of sleep is beneficial. This is surprising since earlier research had shown that sleeps benefits would accrue only if there were 6 hours or more of overnight sleep. We argue that it is the product of slow wave sleep (SWS) and rapid eye movement sleep (REM) that is of importance. Thus shorter than 6 hours of overnight sleep is not

sufficient because of insufficient REM. Afternoon naps are beneficial because they contain significant components of both SWS and REM. Naps earlier in the morning have more REM and later afternoon and evening naps have almost exclusively SWS.

Sara Mednick is following up on this research at the Salk Institute, finding fMRI correlates of the learning as well as showing that it is also specific to particular visual features, not just retinotopic loci. Taken together, it suggests a new way to understand the consolidation of memories in early visual areas.

Role of attention in motor actions

A third major area of research conducted during the grant period was an investigation of the role of attention in the guided motor planning and execution of hand and arm movements. This project has been conducted in collaboration with graduate student, Joo Hyun Song. Our guiding hypothesis was that similar to its role in the initiation of eye movements, motor behavior would be critically dependent of the deployment of focal attention, that rapid hand movements would occur in situations where focal attention was most effectively directed. To investigate these issues we essential built a new laboratory. It consisted of a new eye movement measuring systems and two method to measure arm motions, a touch screen and a hand tracker.

In our first series of studies we found that indeed, for every case where a particular stimulus manipulation has been shown to speed the deployment of visual attention, those same situations also speed manual hand movements. Thus, increasing the number of distractors in a visual search task (Bravo and Nakayama, 1994), repeating target color over trials (Maljkovic and Nakayama, 1994) or introducing a gap between the fixation offset and target appearance (Mackeben and Nakayama,1993) all resulted in speeded arm motions. Detailed measurements of the hand trajectories indicate that these speeded motor acts were reactions can be attributed to two sources, latency to the initiation of the movement and motor execution duration.

Following up on our previous work on the parallel processing of saccadic eye movements McPeek et al., 2000), we asked whether in the motor programming of the arm with such a huge inertial mass in comparison to the eye ball, whether such mid-flight corrections of motor actions would also occur. We hypothesized that these online adjustment would not occur. To our surprise, we found strong evidence for parallel programming of arm motions and that despite the strongly curved trajectories accompanying such changes in direction, little was sacrificed in terms of final target timing or accuracy. This suggests that a simple serial model, with appropriate decisions then followed sequentially by actions is not universally applicable. Instead, wrong initial target trajectories followed by mid flight corrections were very frequent and had very little cost, either in speed or accuracy. In other words, if there is a choice between slow accurate decision making followed by quick direct action vs a much faster choice and error correcting highly curved complex motor trajectories, it seems that our system can opt for the latter in substantial numbers of cases with little cost. We think that the prevalence of fast decisions and large scale corrections needs much more investigation.

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Arni Kristjansson May 2002
Sara C. Mednick May 2003

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